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ABSAROKITE–SHOSHONITE–BANAKITE SERIES.[1]

In the region of the Yellowstone National Park there are igneous rocks of a peculiar type which are associated with the normal andesites and basalts of the region, but which differ from them mineralogically and chemically, and deserves a special classification. The study of these rocks has been carried on in connection with that of all of the igneous rocks of this region, and the present paper is an abstract of a chapter prepared for the report of work done in the Yellowstone National Park by the division of the U. S. Geological Survey under the charge of Mr. Arnold Hague.

The rocks mentioned occur in a number of separate localities within this region, where it is apparent that their generic relations are with normal basalts and andesites, and in each locality the varieties having the peculiarities in question are genetically related to one another by differentiation. But all of these peculiar varieties in the region are not closely related to one another, for they are separate offshoots from distinct reservoirs of magma, and were probably produced by similar processes of differentiation. For purposes of systematic description they may be classified together in a series having certain chemical and mineralogical characteristics. They thus form classes of similar rocks (*i. e.*, like phases of differentiation), that belong to separate, but similar, families of rocks (*i. e.*, groups or series of genetically, hence generically, related differentiation products).

For the most part they are basaltic-looking rocks, occurring as lava flows and dikes, and less often as part of the basic volcanic breccia which constitutes the major portion of the volcanic mountains of the Absaroka Range. They are quite subordinate in amount to the basalts and andesites. As surficial flows they are basaltic in character, being dark colored and heavy, with olivine among the phenocrysts in most cases. They are massive and compact or vesicular. They are porphyritic in some cases, but not noticeably so in others. They generally exhibit a semi-waxy luster that suggests the presence of nepheline, which however is not present. The luster is due to the alkali-feldspars in the groundmass. They are often dull greenish black owing to the serpentinization of olivine. As dikes they are basaltic in some cases, and phonolitic to trachytic in others, being gray in various shades, and having a somewhat waxy luster, due to alkali-feldspars. They are porphyritic or not in different cases, and range from aphanitic to phanerocrystalline.

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[1] Published by permission of the Director of the U. S. Geological Survey.

They present quite a range of composition within limits, and form a series of varieties connected by gradual transitions. They could not be embraced by any one definition and must be divided into several classes.

The chief characteristics of the most basic class are the presence of abundant phenocrysts of olivine and augite, and the absence of phenocrysts of feldspar. The groundmass may be anything from a dark glass to an almost phanerocrystalline, light gray mass. It is oftener aphanitic and dark greenish gray. The phenocrysts are large and pronounced in many cases, but are quite small in others. Chemically they are low in silica, from 46 to 52 per cent.; low in alumina, from 9 to 12 per cent.; high in magnesia, from 8 to 13 per cent.; moderately high in alkalies, with potash higher than soda, except in one case. The molecular ratio of the alkalies to silica is .08 and .09. (See Table I). After the crystallization of abundant phenocrysts of olivine and augite the remainder of the magma, owing to low alumina and relatively high alkalies was so constituted that alkali-feldspathic minerals might crystallize out, which they did or not according to the conditions under which solidification took place.

The principal characteristics of the second class are the presence of phenocrysts of labradorite, augite and olivine, in a groundmass that is usually dark greenish gray, with a semi-waxy luster; but which is sometimes glassy, or phanerocrystalline. The varieties range from those rich in olivine and augite, which with decreasing labradorite grade into rocks of the first class, to varieties poor in olivine and augite. Chemically they range from 50 to 56 per cent. of silica. Alumina is moderate to high, from 17 to 19.7 per cent. Lime and magnesia are moderate to low, the former from 8 to 4.3 per cent., the latter from 4.4 to 2.5 per cent. Alkalies are moderately high with potash comparatively high for rocks of this region with like amounts of silica; potash from 3.4 to 4.4 per cent.; soda from 3 to 3.9 per cent. The molecular ratio of alkalies to silica is .10 and .11. After the crystallization of phenocrysts of labradorite, olivine and augite, the remainder of the magma was rich in alkali-feldspathic material, which shows itself in the groundmass according to the circumstances of solidification.

Rocks corresponding chemically to both of these classes occur without megascopic phenocrysts, and in various phases of crystallization, consequently they differ from them not only in microstructure but in the minerals developed. They occur as lava flows and as dikes, but no special characteristics can be connected with either mode of occurrence, except that the more highly crystallized forms are found as dikes. Not all the dikes, however, are more crystalline than all the lava flows.

Rocks of the third class have been found mostly in dikes. These rocks are highly feldspathic, with smaller amount of ferromagesian minerals, chiefly biotite with subordinate augite. The phenocrysts are labradorite in a groundmass of alkali-feldspars. Chemically they have from 51 to 61 per cent. of silica; 16.7 to 19.6 alumina; 3.5 to 6 per cent. of lime; 1 to 4 per cent. of magnesia; 3.8 to 4.5 per cent. of soda, and 4.4 to 5.7 per cent. of potash. The ratio of alkalies to silica is .13 and .14. Since much of the lime and soda go into the phenocrysts of labradorite, the feldspathic groundmass is rich in potash, and is largely orthoclase. The rocks stand at the end of the series, where labradorite becomes the prevailing phenocryst, and augite and olivine are more or less completely replaced by biotite.

The division of the series into three parts is for convenience. The classes will be described in the order just given under the names: *Absarokite*, *Shoshonite* and *Banakite*.

ABSAROKITE.

All of the rocks here classed as *absarokites* carry abundant phenocrysts of olivine and augite, except two that are included with them on grounds of chemical identity. They occur in the Absaroka range, and in other parts of the Yellowstone Park; at the north base of Sepulchre Mountain; upon Mirror Plateau; within the Crandall volcano; at Signal Point, Yellowstone Lake; at Two Ocean Pass, and in Ishawooa Canyon, and elsewhere. The chemical composition of five of these rocks is shown by the following analysis. Table I.[1]

TABLE I. CHEMICAL ANALYSES OF ABSAROKITES, YELLOWSTONE NATIONAL PARK AND VICINITY.

	1	2	3	4	5
SiO_2	47.28	48.95	48.36	51.76	49.71
TiO_2	.88	.49	1.18	.47	1.57
Al_2O_3	11.56	12.98	12.42	12.36	13.30
Fe_2O_3	3.52	3.63	5.25	4.88	4.41
FeO	5.71	4.68	2.48	4.60	3.37
MnO	.13	.13	.13	.11	.17
MgO	13.17	11.73	9.36	9.57	7.96
CaO	9.20	7.66	8.65	7.14	8.03
BaO	....	....	.29	....	.46
Na_2O	2.89–2.73	2.31	1.46	1.99	1.49
K_2O	2.22–2.17	3.96	3.97	3.83	4.81
P_2O_5	.59	.67	.84	.56	.66
Cl	.18	....	....	....	....
H_2O	2.96	3.16	5.54	3.05	4.07
	100.08	100.35	99.93	100.32	100.01
Less O for Cl	.04				
	100.04				

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[1] Most of the analyses cited in this paper have already been published in the paper by the present writer on the Origin of Igneous Rocks. Phil. Soc. Washington. Bull. Vol. XII. pp. 89–214. Washington, 1892.

1. Leucite-absarokite, Ishawooa Canyon, Wyoming—analyzed by J. E. Whitfield.
2. Absarokite, dike at head of Lamar River—analyzed by L. G. Eakins.
3. Absarokite, dike south of Clark's Fork River—analyzed by L. G. Eakins.
4. Absarokite, lava flow, head of Raven Creek—analyzed by L. G. Eakins.
5. Absarokite, dike, divide east of Cache Creek—analyzed by L. G. Eakins.

The five analyses are arranged according to decreasing percentage of magnesia, the range being a little more than 5 per cent. The alumina increases, the range being less than 2 per cent. Potash increases through a range of 2.6 per cent., while soda and lime have a still smaller range. The second, third and fourth analyses are closely alike. The first and fifth are not so much alike that they might not be considered separately; the chief differences being in magnesia and alkalies. But they are related in other respects. They all exhibit considerable loss upon ignition, corresponding to the amount of hydration due to alteration, or to the presence of zeolitic minerals.

As already remarked the rocks differ somewhat in the mineral composition of the groundmass, as well as in its microstructure. That with the coarsest grain is the one whose chemical composition is given by the first analysis. It was not found in place, so that its exact mode of occurrence is not known, but it is probably an intrusive mass or dike in Ishawooa Canyon, Wyoming. It has already been described by Mr. Hague.[1] It consists of abundant phenocrysts of olivine and augite, 3^{mm} in diameter, and of a subordinate amount of gray crystalline groundmass. In thin section the olivine is colorless and free from inclusions. The augite is pale green, with high extinction angle, reaching 42°. It encloses some olivine and magnetite. The form of these phenocrysts is only partially idiomorphic, the outline being jagged in some cases; the reëntrant angles being occupied by small crystals of orthoclase, whose formation must have been at least contemporaneous with the crystallization of the margins of the olivine and augite. The groundmass consists of crystals of orthoclase and leucite, which are in part idiomorphic, although the mass is holocrystalline, except for occasional possible remnants of glass base. There are also small irregularly shaped crystals of augite and olivine, besides magnetite and much apatite in long, slender needles. Orthoclase and leucite are not uniformly mingled, but are clustered in groups. The orthoclase crystals are rectangular prisms, twinned according to the Carlsbad law. Very rarely they contain minute cores of lime-soda-feldspar, with symmetrical extinction angles of 30°, corresponding to labradorite. The leucites are partly idiomorphic, partly allotriomorphic. In places they are decomposed to a zeolitic mineral. The other constituents of the rock are very fresh. Owing to the small amount of material collected no separations or partial analyses were attempted.

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[1] HAGUE, A. Notes on the occurrence of a leucite rock in the Absaroka Range, Wyoming Territory, Am. Jour. Sci., Vol. XXXVIII., July, 1889.

The rock, whose chemical composition is given by analysis 2, occurs as a four-foot dike on the divide between Lamar River and Crandall Creek. It is dark colored and aphanitic, with abundant phenocrysts of augite, 5 to 10^{mm} in diameter, and smaller ones of olivine. On the sides of the dike the rock is glassy and black. The body of the dike is holocrystalline and very fine grained when seen in thin section. The groundmass consists of indistinctly outlined, lath-shaped feldspars with low extinction angles, there is also an indistinct feldspathic mineral as cement, which is clouded. The lath-shaped feldspars appear to be in part, at least, orthoclase with minute prismatic cores of lime-soda-feldspars. Nothing resembling leucite is present. The feldspathic matrix is crowded with microscopic crystals of augite, magnetite and brown biotite in thin tablets. The groundmass of the glassy margin of the dike is brown glass with microlites of augite and some of lime-soda-feldspar. The augite phenocrysts are light green in thin section and are filled with irregularly shaped inclusions of crystalline groundmass containing rods of ilmenite. There are also inclusions of small olivines and magnetite. The olivine phenocrysts are idiomorphic and quite fresh, with small inclusions of magnetite and glass, and occasionally bays of groundmass.

The glassy groundmass of the margin of the dike is unlike the groundmass of the central part in mineral composition. Biotite is not present, and the only feldspars are microlites of plagioclase, which may correspond to the prismatic cores in the small orthoclases of the central part of the dike.

When compared with the leucite-absarokite from Ishawooa Canyon it is found that the phenocrysts of olivine and augite are not so abundant as in that rock, while there is much more augite in the groundmass, besides abundant biotite. The microscopic feldspars are not so large and distinct, and leucite is wanting. Chemically the rock just described is richer in potash, with about the same soda. Alumina is slightly higher; and magnesia and lime slightly lower. Silica is a little higher. The high percentage of water indicates a hydrous silicate in the groundmass.

The rock, whose chemical composition is shown by analysis 3, forms a 3-foot dike on the high ridge south of Clark's Fork River, southeast of Index Peak. The rock corresponding to analysis 4 forms a surficial lava flow east of the head of Raven Creek on Mirror Plateau. Chemically they are almost identical, and nearly the same as the dike rock from the divide between Lamar River and Crandall Creek. They have slightly less magnesia, and the lava flow has 3.4 per cent. more silica than the dike rock. The dike rock is dark greenish gray, aphanitic, with small megascopic phenocrysts of augite, and occasional large crystals of quartz with augite shells. In thin section the few megascopic augites resemble those in the rock last described. All the other constituents may be considered as parts of the holocrystalline groundmass. They are abundant pale green augite, brown biotite and magnetite with a subordinate amount of feldspathic matrix. There are larger augites, colorless at the center and green at the margin, besides many small serpentinized olivines. The feldspar is partly lath-shaped orthoclase with prismatic cores of lime-soda-feldspars. They are often in radiating groups. There is also much cloudy microcryptocrystalline material with no definite form, except a frequent approach to the outline of an isometric mineral. These are often darker colored at the center, and suggest altered leucites. The large loss upon ignition and the presence of leucite in similar rocks in this region render this highly probable. Some parts of the rock contain what is undoubtedly analcite. The occasional large quartz crystals have the character of primary crystals. Their possible association with leucite is indicated, but no leucite has been actually observed in the rock.

This rock resembles the dike rock from the divide at the head of Lamar River in the general character of the groundmass, except that the phenocrysts of olivine and augite are almost microscopic, and may be considered as part of the groundmass. The ferromagnesian minerals are about the same in each, and the feldspathic components are obscure, with indications of alkaline character.

The rock of the lava flow at the head of Raven Creek is dark gray with abundant small megascopic phenocrysts of olivine and augite. In thin section these minerals resemble those in the rocks already described. The groundmass consists of small rectangular prisms of orthoclase, sometimes with minute cores of prismatic labradorite; besides abundant microscopic crystals of augite and magnetite, there is a little serpentine. The feldspars are distinctly crystallized and their character as orthoclase is unquestionable. They resemble the orthoclase in the leucite-absarokite from Ishawooa Canyon. No leucite, however, was observed in this rock. Only a very small part of the groundmass is lime-soda-feldspar. There is no biotite, and no analcite. Apatite occurs in delicate needles. The absence of biotite may be correlated with more pronounced orthoclase and abundant olivine; and the absence of leucite accords with the higher percentage of silica.

The rock, whose composition is shown by analysis 5, occurs as a narrow dike on the divide east of Cache Creek. It is brownish gray and aphanitic, without phenocrysts, but having minute brown pseudomorphs, presumably after olivine. There are occasional rounded grains of dark colored, crackled quartz, surrounded by a thin, green shell. In thin section the rock is fine grained and holocrystalline, consisting of thin prisms of feldspar, frequently grouped in fan-like clusters. They are not distinctly striated, and are probably orthoclase. Others are lime-soda-feldspars, with low extinction angles, and some are irregularly bounded and are obscure. This matrix is crowded with idiomorphic crystals of pale green augite, dark brown biotite and magnetite. Some of the biotite crystals are long, narrow plates, resembling prisms of hornblende, for which mineral they were at first mistaken. There is considerable serpentine scattered through the rock.

Mineralogically this rock is very similar to the dike rock south of Clarks Fork River. Chemically, it is slightly higher in alumina and potash and lower in magnesia and lime. The high loss on ignition is probably due in this case to the serpentinization of the olivine.

There are other rocks of this class in the region, but they will not be described here. Transitional varieties between absarokite and normal basalts occur, as well as transitions to shoshonite.

SHOSHONITE.

The rocks classed as shoshonites are more numerous than the absarokites, and embrace a somewhat wider range of composition. They occupy the middle ground, as it were, in the series and pass by transitional varieties into absarokite, banakite and into normal basalt. They occur associated with absarokite, and consequently at the same localities: on the Lamar River, Mirror Plateau, Crandall Basin, at various localities in the Absaroka Range, and at Two Ocean Pass, one of the divides at the head of Shoshone River. From this locality the rock was first collected and identified as an orthoclase-bearing basalt. Shoshonites also occur in the northwestern portion of the Yellowstone Park. Most of these rocks are characterized by prominent phenocrysts of labradorite, together with those of augite and olivine. But some are without megascopic phenocrysts and are correlated with the porphyritic forms on chemical as well as mineralogical grounds. A small number are leucite-bearing.

The chemical composition of five of these rocks is given in Table II. The analyses are arranged so as to bring those most alike by the side of one another. The range of silica is 6 per cent. Alumina is moderately high. Magnesia, with a range of less than 2 per cent., is rather low for basic rocks. Lime, with a range of less than 4 per cent. is moderate. Soda is almost constant; and potash is relatively high, with a range of only 1 per cent. The loss upon ignition is comparatively high for all the rocks analyzed. As already mentioned, the mineralogical variation is from an abundance of olivine and augite to a paucity of them, with inverse variation in the feldspars. This accords with the variations in the chemical composition.

TABLE II. CHEMICAL ANALYSES OF SHOSHONITES, YELLOWSTONE NATIONAL PARK AND VICINITY.

	1	2	3	4	5
SiO_2	50.06	53.49	52.49	54.86	56.05
TiO_2	.51	.71	.81	.69	.98
Al_2O_3	17.00	17.19	17.89	17.28	19.70
Fe_2O_3	2.96	4.73	5.76	4.08	3.74
FeO	5.42	3.25	2.08	2.28	2.32
MnO	.14	.14	.09	.19	tr.
MgO	3.61	4.42	3.49	4.19	2.51
CaO	8.14	6.34	7.01	5.42	4.34
BaO	..	.06	.30	.37	..
Na_2O	3.53	3.23	3.18	3.94	3.29
K_2O	3.40	3.86	3.73	3.96	4.44
P_2O_5	.66	.43	.55	.48	.66
H_2O	4.85	2.17	2.63	2.16	1.86
	100.28	10.002	100.01	99.90	100.14

1. Shoshonite, lava sheet, Lamar River, south of Bison Peak; analyzed by L. G. Eakins.
2. Shoshonite, lava sheet, S. E. fork of Beaverdam Creek; analyzed by L. G. Eakins.
3. Leucite (?) -shoshonite, lava sheet, mountain east of Pyramid Peak; analyzed by L. G. Eakins.
4. Olivine-free shoshonite, dike N. E. of Indian Peak; analyzed by L. G. Eakins.
5. Shoshonite, lava sheet, Two Ocean Pass; analyzed by J. E. Whitfield.

The rock of analysis 1 is a surficial lava on Lamar River, south of Bison Peak. It is dark gray, with a waxy luster, and has abundant phenocrysts of labradorite, augite and olivine; also some small amygdules of zeolite and calcite. In thin section it is holocrystalline, the groundmass consisting of lath-shaped lime-soda-feldspar and considerable orthoclase in zones surrounding the plagioclase microlites, and also in twinned prisms. There are besides augite, magnetite and a little serpentine. The phenocrysts of labradorite are twinned with very narrow lamellæ. Those of augite and olivine are like the phenocrysts of these minerals in absarokite.

The rock of analysis 2 forms a massive lava sheet on the southeast fork of Beaverdam Creek. It is dark purplish gray, with numerous phenocrysts of labradorite, augite and serpentinized olivine. A lighter colored variety carries porphyritical biotite and amygdules of zeolite. In thin section it is holocrystalline, and resembles the rock just described very closely, except that the olivine is serpentinized. The groundmass is similar to that of the former, and there is considerable orthoclase. In the variety with biotite there are cloudy patches of an isotropic mineral, which may be analcite. The lava sheet immediately overlying this one is similar to it in general appearance, but contains leucite, and is somewhat more alkaline (analysis 5, Table III), and will be described in connection with banakite.

The rock of analysis 3 is a surficial lava flow occurrring on the top of the table mountain east of Pyramid Peak. In general appearance it resembles the shoshonite from Lamar River south of Bison Peak (analysis 1), but the phenocrysts are fewer and smaller. The rock is holocrystalline and very fine-grained, with an abundance of microlites of augite and magnetite. The microscopic feldspars are lath-shaped crystals and allotriomorphic grains with low double-refraction. There are spots where minute grains of augite and magnetite are clustered together and are inclosed in a yellowish substance which is almost isotropic, and has the outline of leucite. These impure leucites are scattered through the rock and are not very numerous. They are very minute and cannot be more definitely identified. The groundmass carries irregular patches of light brown mica, small phenocrysts of augite and of serpentinized olivine, and still fewer larger crystals of augite and olivine, but none of labradorite. The rock is a leucite-bearing modification of shoshonite magma, without noticeable difference in the chemical composition.

The rock of analysis 4 forms a narrow dike on the ridge northeast of Indian Peak, Crandall Basin. It is gray and aphanitic, with abundant small phenocrysts of augite and lime-soda-feldspar with rather low extinction angles. It is very fine grained and holocrystalline, consisting of indistinctly outlined feldspar microlites, in part alkaline with low double-refraction and no polysynthetic twinning. There is a subordinate amount of biotite in idiomorphic microlites, besides prisms of augite and grains of magnetite. Olivine is absent, in which respect it differs from other varieties of these rocks. Chemically it is very similar to the shoshonite from Beaverdam Creek (analysis 2).

The rock of analysis 5 is the uppermost of five lava sheets that overlie one another at Two Ocean Pass. It is dark gray, with a waxy luster, and carries scattered phenocrysts of feldspar and serpentinized olivine. In thin section the rock is seen to be holocrystalline; the groundmass consisting of orthoclase in idiomorphic and also in allotriomorphic crystals, with much magnetite and augite, and some chlorite or serpentine, besides red-brown biotite, and hairlike needles of apatite. There are also comparatively large, but microscopic, dusted apatites among the phenocrysts, showing this mineral in two generations, or periods of crystallization. Some of these apatites are enclosed in olivine, which is completely serpentinized. The feldspar phenocrysts are labradorite, with highly developed polysynthetic twinning. In the rock of the second sheet at this place the feldspar phenocrysts are labradorite-bytownite, being decidedly basic with high extinction angles, and relatively strong double-refraction. The groundmass is like that of the overlying shoshonite, just described, except that the orthoclase crystals sometimes have a small nucleus of lime-soda-feldspar. Another one of these five sheets of lava is shoshonite like the last two mentioned.

BANAKITE.

The most feldspathic rocks of this series, which occur as dikes associated with dikes of shoshonite and absarokite, are not so numerous, although more of them have been analyzed. They occur in Crandall Basin, in Ishawooa Canyon and near the head of Stinkingwater River. A leucite-bearing variety forms a lava sheet near Beaverdam Creek. Their chemical composition is shown by the analyses in Table III.

TABLE III. CHEMICAL ANALYSES OF BANAKITES. YELLOWSTONE NATIONAL PARK AND VICINITY.

	1	2	3	4	5	6	7
SiO_2 -	51.82	52.63	51.46	52.33	52.93	57.29	60.89
TiO_2 - -	.71	.81	.83	.71	.72	.72	.49
Al_2O_3 -	16.75	16.87	18.32	18.70	19.67	18.45	17.14
Fe_2O_3 -	4.56	4.52	4.61	4.95	3.07	4.38	3.32
FeO -	3.36	3.11	2.71	1.83	3.50	1.20	.95
MnO - -	.23	.10	.17	.03	.15	tr.	.09
MgO -	4.03	3.69	2.91	2.69	2.88	2.08	1.16
CaO - -	4.94	4.77	6.03	4.71	4.69	3.57	3.58
BaO -	.26	.29	....	....	.21	....	....
Na_2O -	3.91	3.86	4.11	4.51	4.20	4.43	4.54
K_2O -	5.02	5.17	4.48	5.45	4.75	5.43	5.71
P_2O_5 - -	.52	.63	.86	.81	.59	.46	.27
NiO -	....	....	....	.14	....	.12	.19
H_2O - -	3.97	3.65	3.89	3.45	2.73	2.18	1.61
	100.08	100.10	100.38	100.31	100.09	100.31	99.94

1. Banakite, dike, head of Lamar River, analyzed by L. G. Eakins.
2. Banakite, dike, Hoodoo Mountain, analyzed by L. G. Eakins.
3. Banakite, dike, Ishawooa Canyon, analyzed by L. G. Eakins.
4. Banakite, dike, near head of Stinkingwater River, analyzed by W. H. Melville.
5. Leucite-banakite, lava sheet, southeast fork of Beaverdam Creek, analyzed by L. G. Eakins.
6. Quartz-banakite, dike, near head of Stinkingwater River, analyzed by W. H. Melville.
7. Quartz-banakite, dike, near head of Stinkingwater River, analyzed by W. H. Melville.

The rocks of analyses 1 and 2 form dikes; the first occurring on the divide between Lamar River and Crandall Creek, and the second on the south slope of Hoodoo Mountain. The two dikes trend in the same direction and are possibly one continuous body. The rocks are alike chemically and mineralogically and may be described together. They are light gray and aphanitic, with a waxy luster. There are prominent phenocrysts of augite and rusted spots of serpentinized olivine, but none of feldspar. In the rock from Hoodoo Mountain there are amygdules of white stellate zeolite. In thin section the rocks are seen to be holocrystalline with more feldspar than ferromagnesian minerals. The feldspars are in part lath-shaped, in part tabular. They are simple twins, and are orthoclase with kernels of plagioclase which is mostly altered, the centers of the crystals being decomposed in many cases. There is considerable serpentine scattered through the rock. The ferromagnesian minerals are augite, biotite, magnetite, with some ilmenite in rod-like shapes. Apatite occurs in needles. There is considerable analcite, which partly occupies former cavities or cracks, and partly has outlines suggesting former isometric minerals. The dike on the divide at the head of Lamar River is immediately alongside of the dike of absarokite whose chemical composition is given by analysis 2 of Table I.

The rock of analysis 3 is quite similar to those just described but is still more feldspathic. It forms a dike in the Ishawooa Canyon. It is dark gray and waxy looking with tabular phenocrysts of feldspar and many smaller ones. It is holocrystalline, and consists of abundant lath-shaped twins of orthoclase having a rectangular kernel of labradorite, whose symmetrical extinction angles correspond to a composition of $An_3 Ab_2$. There is an isotropic cement between the feldspars which may be analcite or sodalite. Biotite and augite are abundant in small crystals, besides magnetite and a little serpentine, which appears to have been derived from small olivines. The phenocrysts are labrodorite ($An_2 Ab_3$), some of which have borders of orthoclase. Sodalite is possibly present among the phenocrysts.

The rock of analysis 4 is closely related to the last. It forms a dike near the head of Stinkingwater River. It carries more phenocrysts of serpentinized olivine, and is coarser grained, though still microcrystalline. The feldspars are more altered and less distinct. The mineral composition is like the last rock described, but a few of the augites are bright green, indicating an approach to aegerite-augite.

The rock of analysis 5 is a leucite-bearing variety of banakite, already mentioned as forming a massive surficial lava flow immediately overlying the shoshonite whose chemical composition is given by analysis 2 of Table II., and which occurs on the southeast fork of Beaverdam Creek. Its chemical composition is but slightly different from that of the rock last described (analysis 4). The rock is dark gray with a somewhat waxy luster. It carries small phenocrysts of feldspar, serpentinized olivine and a few of augite. It is holocrystalline with a groundmass of microscopic leucites and unstriated feldspars which appear to be orthoclase, but may be plagioclase with low angle of extinction. There are also microscopic augites and magnetite, and some serpentine, besides a few patches of light brown mica. The phenocrysts are labradorite, serpentinized olivine and fewer augites, magnetites and stout apatites. The crystals of leucite have the characteristic form and inclusions, and in places are somewhat altered. This rock grades into denser, finer grained forms, and also into vesicular forms, which have the same mineral composition as the more crystalline part of the mass. Mineralogically the rock is more suggestive of shoshonite than of banakite, owing to the paucity of biotite and more numerous olivines. But the amount of ferromagnesian minerals is smaller than in shoshonite, and the proportion of alkaline-feldspathic minerals greater, which corresponds to the chemical composition.

The rocks of analyses 6 and 7 belong to this series both mineralogically and chemically, but are somewhat more siliceous, having 5 to 9 per cent. more silica. They might properly be given specific names, but at present we prefer to class them with banakite, under the name of *quartz-banakite*, the amount of quartz however being very small.

The two rocks analyzed are closely alike in alkalies and lime, but the first one is lower in silica and slightly higher in alumina, iron oxide and magnesia. They differ somewhat in mineral composition, though both are characterized by abundant feldspar and biotite.

The first one (analysis 6) is a gray rock, distinctly crystalline with a few megascopic crystals of feldspar and mica. It is holocrystalline, and is composed of lath-shaped, rectangular and allotriomorphic feldspars, with considerable brown biotite, besides magnetite and a little augite, partly decomposed. There is a very little quartz and calcite. The central portion of the crystals of feldspar is lime-soda-feldspar, in some cases labradorite. The marginal portion is orthoclase which forms a considerable part of the crystal, but is subordinate in amount to the plagioclase.

The second rock (analysis 7) is light-gray with numerous small tabular feldspars and some large ones, besides a few phenocrysts of biotite. The rock is holocrystalline and nearly panidiomorphic, the feldspars of the groundmass being in small, rectangular to lath-shaped crystals with fluidal arrangement. The groundmass also contains a small amount of biotite, very little magnetite and augite, and some colorless apatite. The feldspar phenocrysts are labradorite, while the feldspar of the groundmass is mainly orthoclase with kernels of fresh feldspar that has the optical characters of oligoclase. There is very little quartz and a little chlorite or serpentine.

The mineralogical analogy between banakite and shoshonite is chiefly in the association of phenocrysts of labradorite with microlites of orthoclase. Biotite and augite occur in some rocks of both classes, while olivine is present in one variety of banakite, and is common to most shoshonites. These banakites are not properly minettes on account of the prominence of labradorite, and they differ from kersantites by the presence of orthoclase in the groundmass. They bear the same relation to kersantite that shoshonite bears to normal basalt. They are the highly feldspathic modifications of shoshonite magma, and are complementary to absarokite, which represents the least feldspathic modification of the same magma.

A comparison of the chemical analyses of the rocks of this series, besides making evident the relationships already noted, also shows what mineralogical differences may obtain for rocks of nearly the same chemical composition. Some of these differences have already been described in the case of the leucite-bearing varieties. Other differences may be mentioned. Comparing the shoshonite lava flow from the south base of Bison Peak (analysis 1, Table II.) with the banakite dike rock from Ishawooa Canyon (analysis 3, Table III.), we find in the first, abundant phenocrysts of labradorite, augite, and olivine; while in the second, numerous phenocrysts of labradorite, but few and small ones of augite and olivine. The groundmass of the first shows much less orthoclase than that of the second, and no biotite, which abounds in the second. The latter contains what is probably analcite. The shoshonite lava flow from the south-east fork of Beaverdam Creek (analysis 2, Table II.), and the shoshonite dike rock from the ridge northeast of Indian Peak (analysis 4, Table II.), though nearly alike chemically, are quite unlike mineralogically. The first has abundant phenocrysts of labradorite, olivine and augite, while the second contains no olivine. The groundmass of the second contains some brown biotite, which may be secondary, while that of the second contains much biotite that is primary. In each pair of cases we find olivine more abundant in the surficial rock, and biotite more abundant in the dike rock, or these minerals may be entirely absent in one case or the other.

Similar rocks in neighboring regions.—Rocks almost identical with absarokite occur in the region of Bozeman, Montana, and have been described by Professor Merrill,[1] whose work was reviewed in the last number of this Journal.[2]

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[1] MERRILL, G. P. Notes on some Eruptive Rocks from Gallatin, Jefferson and Madison counties, Montana. Proc. U. S. Nat. Mus., Vol. XVIII., pp. 637–673 (No. 1031), Washington, 1895.

[2] JOURNAL OF GEOLOGY, Vol. III., No. 7, p. 850, Chicago, 1895.

The chemical composition of these rocks is shown by the first four analyses in Table IV., taken from Professor Merrill s paper.

TABLE IV. CHEMICAL ANALYSES OF IGNEOUS ROCKS CORRESPONDING TO ABSAROKITE AND SHOSHONITE.

	1	2	3	4	5	6	7
SiO_2	46.90	49.13	50.82	51.65	50.03	52.33	54.15
TiO_2	.41	.42	.59	.55	.61	.14	....
Al_2O_3	10.17	9.05	11.44	13.89	14.08	15.09	18.92
Fe_2O_3	1.22	3.57	.25	2.70	2.92	4.31	6.79
FeO	5.17	5.05	8.94	4.80	6.11	4.03	
MnO	.10	.15	.19	.15	.08	.09	....
MgO	20.98	17.21	14.01	11.56	10.73	6.73	1.90
CaO	6.20	5.68	8.14	4.07	7.46	7.06	3.72
BaO	....	.05	.06	.19	.04	.07	....
Na_2O	1.16	2.01	1.79	2.99	1.46	3.14	5.47
K_2O	2.04	2.24	3.45	4.15	2.64	3.76	8.44
P_2O_5	.44	.38	.20	.21	.42	1.02	....
Cr_2O_3	.33	.39	.03	.80	tr.	....	....
SO_3	....	....	....	.19	....	....	Cl .42
H_2O at 110°	1.04	.84	....	1.30	....	2.68	....
Ign.	4.38	3.50	.58	1.89	3.70	....	not det.
	100,54	99.87	100.49	101.09	100.28	100.45	99.81

1. Fort Ellis, 2½ miles southeast of Bozeman, Montana—analyzed by T. M. Chatard
2. Bear Creek, Madison Valley, Montana—analyzed by T. M. Chatard.
3. South Boulder and Antelope Creek, Montana—analyzed by L. G. Eakins.
4. Cottonwood Creek, Montana—analyzed by T. M. Chatard.
5. Cottonwood Creek, " —analyzed by L. G. Eakins.
6. Cottonwood Creek, " —analyzed by L. G. Eakins.
7. Cottonwood Creek, " —analyzed by G. P. Merrill.

The variability of these rocks within certain limits is evident; the greatest range being in magnesia. As a class they are characterized by low silica and alumina, high magnesia, comparatively high alkalies, with much potash. The rock of the fifth analysis is a transitional variety, between absarokite and normal basalt. The sixth analysis is from a rock corresponding somewhat to shoshonite, in alkalies, but slightly lower in alumina, and higher in lime and magnesia. It is associated with the rocks of analyses 4 and 5. It has nearly the chemical composition of the rock called yogoite by Pirsson. Associated with the absarokites in several places are highly feldspathic rocks, richer in alkalies than the banakite of the Yellowstone Park. The chemical composition of one of them is shown by analysis 7, of Table IV. They are undoubtedly complementary products of differentiation.

In the Highwood and Little Belt Mountains of Montana there are rocks almost the same as absarokite in chemical composition, but coarsely crystalline. They have been described by Weed and Pirsson,[1] the account of the rocks of Yogo Peak having just been published. The chemical composition of the rocks of Yogo Peak and those of the two rocks of Square Butte, Highwood Mountains, is shown by the analyses in Table V. taken from the articles cited.

Pirsson states that the three rocks from Yogo Peak grade into one another, and are facies of one mass, whose variations are the result of differentation. They are granular crystalline, and consist essentially of orthoclase and augite in different proportions, and with subordinate amounts of plagioclase, biotite, magnetite; and in the syenite, hornblende; and in shonkinite, olivine, besides accessory minerals. In the syenite orthoclase exceeds augite, in yogoite orthoclase equals augite, and in shonkinite augite exceeds orthoclase. Chemically the series is characterized by comparatively low alumina, with relatively high potash, which is nearly constant. The sum of the alkalies decreases with decrease of silica and alumina. Magnesia and lime are fairly high. In the two rocks of Square Butte the shonkinite is like that of Yogo Peak, but alumina and alkalies are somewhat lower, and magnesia and lime higher. The syenite of Square Butte, the complementary rock with shonkinite, is high in alumina and alkalies, and very low in magnesia and lime, with very high potash. In these two cases we find shonkinites as extreme forms of differentations in connection with syenitic rocks quite different from one another in chemical composition, one being comparatively low in alumina and the other high, the sum of the alkalies in one case being 8.85 per cent., and in the other 12.74 per cent. In each instance the associated rocks are facies of one igneous mass.

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[1] WEED, W. H. and PIRSSON, L.V., Highwood Mountains of Montana. Bull. Geol. Soc. America. Vol. VI., pp. 389-422. Rochester, 1895. Reviewed in this JOURNAL. Vol. III., No, 7, p. 851; also Igneous Rocks of Yogo Peak, Montana. Am. JOUR. Sci., Vol., L., No. 300. Dec. 1895. pp. 467–479.

TABLE V. CHEMICAL ANALYSES OF IGNEOUS ROCKS FROM YOGO PEAK AND SQUARE BUTTE, MONTANA.

	Yogo Peak.			Square Butte.	
	1	2	3	4	5
SiO_2	61.65	54.42	48.98	46.73	56.45
TiO_2	.56	.80	1.44	.78	.29
Al_2O_3	15.07	14.28	12.29	10.05	20.08
Fe_2O_3	2.03	3.32	2.88	3.53	1.31
FeO	2.25	4.13	5.77	8.20	4.39
MnO	.09	.10	.08	.28	.09
MgO	3.67	6.12	9.19	9.68	.63
CaO	4.61	7.72	9.65	13.22	2.14
BaO	.27	.32	.43	....	....
Na_2O	4.35	3.44	2.22	1.81	5.61
K_2O	4.50	4.22	4.96	3.76	7.13
P_2O_5	.33	.59	.98	1.51	.13
Cr_2O_3	tr.	tr.	tr.	....	....
SrO	.10	.13	.08	....	....
Li_2O	tr.	tr.	tr.	tr.	....
Fl	....	....	.22	Cl .18	.43
H_2O at 110°	.26	.22	.26	1.24	1.77
H_2O above 110°	.41	.38	.56		
	100.15	100.19	99.99	100.97	100.45
		O=Fl	.08	O=Cl .04	.10
			99.91	100.93	100.35

1. Syenite, Yogo Peak, analyzed by W. F. Hillebrand.
2. Yogoite, Yogo Peak, analyzed by W. F. Hillebrand.
3. Shonkinite, Yogo Peak, analyzed by W. F. Hillebrand.
4. Shonkinite, Square Butte, analyzed by L. V. Pirsson.
5. Sodalite-syenite, Square Butte, analyzed by W. H. Melville.

In his account of the rocks of the grorudite-tinguaite series,[1] Professor Brögger describes a series of igneous rocks occurring as dikes that are characterized by mineralogical and chemical peculiarities, which distinguish them from all other rocks in the Christiania region, and which warrant their being separated into distinct classes. These have been named grorudite and sölvsbergite, the third member of the series being tinguaite. Between these classes are transitional varieties. The rocks of this series grade through mineralogical and chemical transitions into other rocks belonging to different series, such as laurvikite, laurdalite, nordmarkite and soda-granite. They represent a series of particular phases of differentiation of genetically related magmas, as in the case of the series described from the Yellowstone Park.

The chemical composition of the rocks in the grorudite-tinguaite series, as given by Brögger, is shown in Table VI. The whole series is more siliceous than those we have been considering, the range of silica being from 56.58 to 74.35 per cent. Some of the marked characteristics of this series are the strong decrease in alumina with increase of silica; also the corresponding increase in ferric oxide; the relatively high percentage of alkalies which increase with alumina, soda being greater than potash. Magnesia and lime are very low. The mineral characteristics are equally marked.

The consistent minerals are potash-feldspar and soda-feldspar, with ægerite (or alkaline hornblende) with quartz in some cases, without it in others, and with nepheline in others. Plagioclase is entirely wanting, and mica and hornblende are generally scarce. The chemical character of the series is distinctly different from that of the series of rocks just described from Yellowstone Park and Montana. A comparison of these series shows to what extent the products of differentiation in various regions may differ from one another, the laws of variation being quite opposite sometimes. Hence natural series of rocks, which may be genetically related, may traverse any scheme of sys-

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[1] Brögger, W. C. Die Eruptivgesteine des Kristianiagebietes. 1. Die Gesteine der Grorudit-Tinguaite-Serie. Kristiania, 1894.

TABLE VI. CHEMICAL ANALYSES OF GRORUDITE, SÖLVSBERGITE, TINGUAITE.

	1	2	3	4	5	6	7	8
SiO_2	74.35	70.15	71.35	68.95	64.92	62.70	58.90	56.58
$TiO_2(+ZrO_2)$....		.65	.50	.35	tr.	.92	.40	....
Al_2O_3	8.37	10.60	12.21	14.00	16.30	16.40	17.70	19.89
Fe_2O_3	5.84	5.77	4.53	2.12	3.62	3.34	3.94	3.18
FeO	1.00	1.74	1.14	3.56	.84	2.35	2.37	.56
MnO	.22	.52	.78	.55	.40	tr.	.55	.47
MgO	.07	.35	tr.	.07	.22	.79	.54	.13
CaO	.45	.72	.22	.23	1.20	.95	1.05	1.10
Na_2O	4.51	5.30	6.51	5.45	6.62	7.13	7.39	10.72
K_2O	3.96	4.09	3.22	5.29	4.98	5.25	5.59	5.43
H_2O	.25	tr.	0.33	.05	.50	.70	1.90	1.77
	99.38	99.89	100.89	100.62	99.60	100.10	100.33	99.83

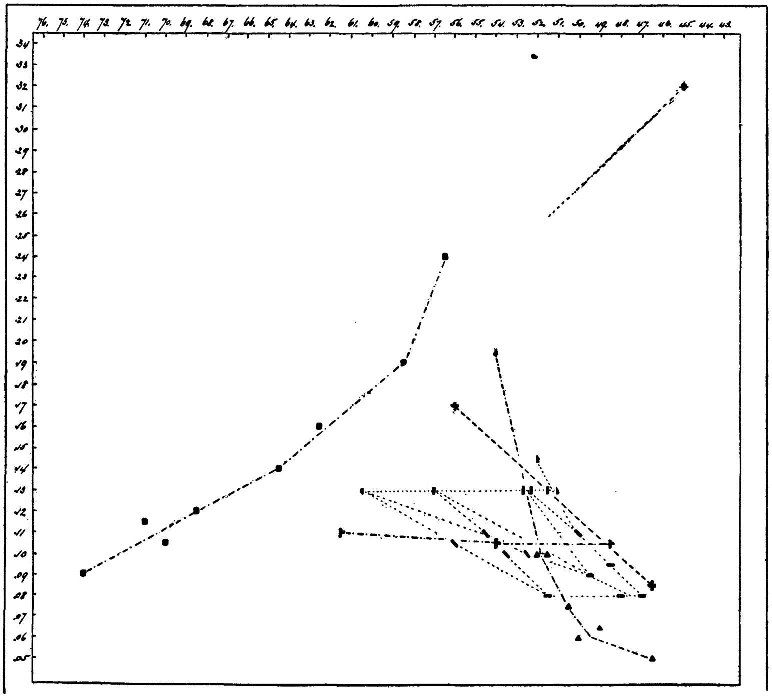
1. Grorudite, Varingskollen, Norway.
2. Grorudite, Grorud, "
3. Grorudite, Kallerud, "
4. Grorudite, Frön, "
5. Quartz-bearing Sölvsbergite, "
6. Nearly quartz-free Sölvsbergite, Lougenthal, Norway.
7. Nephelin-bearing Sölvsbergite, Tjose-Aklungen, Norway.
8. Tinguaite, Hedrum, Norway.

tematic classification of igneous rocks in various directions. This may be shown graphically as in the accompanying diagram, where the series of analyses are plotted so as to bring out the relation between the total alkalies and the silica in each case. The grounds for this method of comparison will not be gone into at this time, owing to lack of space, only the results can be given. The molecular proportion between the sum of the alkalies and silica in each case is expressed in parts of a hundred, which are used as ordinates. The silica percentages are used as abscissas, the highest being placed at the left. Hence the most silicious rocks are at the left hand end of the diagram, and those with the smallest ratio of alkalies to silica at the bottom. The rocks with least alkalies are at the lower right hand corner of the diagram. The location of the various rocks in such a scheme is indicated by different symbols.

DIAGRAM SHOWING THE RANGE IN ALKALI-SILICA RATIOS

$$\left(\frac{Na_2O + K_2O}{SiO_2}\right)$$

IN CERTAIN GENETICALLY RELATED SERIES OF IGNEOUS ROCKS.



▪ Grorudite-Tinguaite Series, Christiania region.
✦ Nepheline-Porphyry, Beemersville, N. J.
✚ Shonkinite-Sodalite-Syenite Series, Square Butte, Montana.
† Shonkinite-Yogoite-Syenite Series, Yogo Peak, Montana.
▴ Absarokite-Sodalite-Syenite Series, Bozeman District, Montana.
| Banakite ⎫
⟍ Shoshonite ⎬ Series, Yellowstone National Park.
▬ Absarokite ⎭

The grorudite-tinguaite series traverses the diagram in an almost straight line, which rises steeply from the most siliceous end to the least siliceous, the alkali-silica ratio ranging from .09 to .24. The location of the so-called Sussexite, from Beemersville, Sussex county, N. J., which Brögger considers equivalent to a possible extreme form of differentiation belonging to this series, occurs in the diagram in direct line with the trend of the grorudite-tinguaite analyses. The alkali-silica ratio being .32.

The few analyses of the differentiation facies of the igneous cores at Square Butte and Yogo Peak are merely indications of the trend of these series. In fact at Square Butte, there are simply the two end results of highly advanced differentiation. The trend of the line connecting these extremes is almost at right angles to that of the grorudite-tinguaite series. The trend of the line connecting the three parts of the Yogo Peak mass is almost horizontal. The two analyses of shonkinite lie close together, but those of the complementary syenitic rocks are separated from one another by considerable space. Assuming that the sodalite-syenite and absarokites described by Professor Merrill are complementary rocks, as their association in the field and their analogy with the rocks of Square Butte indicate, we find a line connecting their possible series would be nearly vertical, as in the diagram. The analysis of the rocks of the absorakite-shoshonite-banakite series occupy a rather broad belt in the diagram, which lies between the extreme of the Yogo Peak and Square Butte series. The least siliceous absarokites lying very near shonkinite and the quartz-banakites lying between the syenites of these series. From the position of the analyses in the diagram it is evident that the absarokite-banakite series as here constituted is more comprehensive than either of the two above mentioned, which are in fact distinct series, since each is confined to a particular rock mass. But in the case of the dikes and lavas in the Yellowstone Park no such subdivision of these orthoclase-bearing, basic rocks could be established. Occurring as they do as a group of related lavas, having like geological relations, and analogous chemical and mineral compositions, they must naturally be considered as a series variable in two principal directions chemically: in the ratio of alkalies to silica, and also in the silica percentages. The variations of the other chemical constituents are to some extent functions of these variables. In a region where highly differentiated igneous rocks occur as disconnected geological bodies in great numbers, it might always be possible to select some particular series of isolated rocks as a genetic series, from which a law of differentiation might be derived. But it would seem that the several instances of "laccolithic differentiation" described by Pirsson must be the surest basis upon which definite laws may be established. And on the other hand, anything like the frequent occurrence of differentiated lavas in a region must involve a multiplicity of lines of differentiation which cannot be disentangled, and which must of necessity be treated collectively. As Professor Brögger observes in the work already quoted the various members of the grorudite-tinguaite series in the Christiania region are mostly disconnected rock masses, and are probably related genetically with rocks differing slightly from them in chemical composition, so that members of a parallel series, differing in its general character from the one described, may be genetically more closely related to certain members of the first series, than to some members of the chemical series in which they may have been placed.

The question how far the genetic relationships between igneous rocks can be made to serve as a basis of classification is an open one. They certainly constitute the foundation of a genealogy of igneous rocks, but it may be doubted whether they can properly mark the lines along which a systematic classification can be established.

JOSEPH P. IDDINGS.